



THE NEW TRAMWAY

Peter J. Walker

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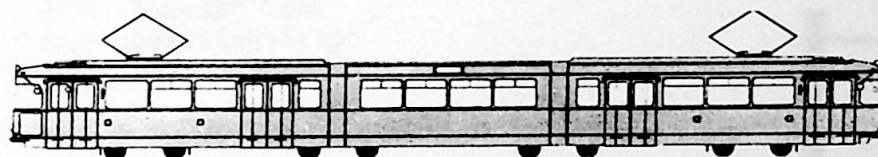
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THE NEW TRAMWAY

The Case for Light Railway Rapid Transit

by Peter J. Walker, Dip. Arch.(Birm.), ARIBA

Hon. Overseas Editor, 'Modern Tramway'



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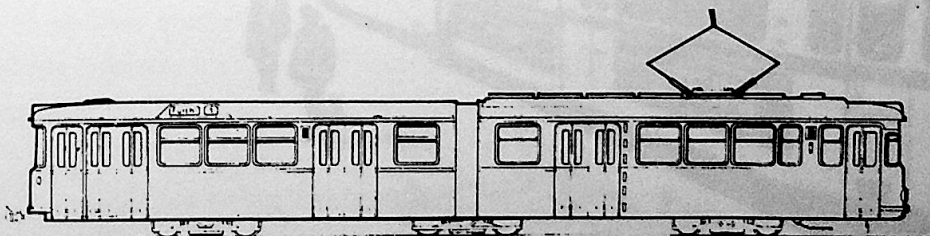
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AUTHOR'S FOREWORD

In the last few years, the need for new public transport installations has become recognised in this country by planners and engineers. The Light Railway Transport League has received several requests for information on tramways and light railways which it has been glad to provide. As there is still little technical literature available on this subject, this work is intended as a general introduction, but further information is available on request from the LRTL. Assistance in the preparation of the work is gratefully acknowledged from fellow-members, especially Mr. W.J. Wyse, B.Sc.

Because of the mixed associations of the term 'tramway' and some possible misconceptions of our notions of a 'modern tramway', a definition should precede any description or discussion of the subject. By 'tramway' we understand a railway constructed or operated to standards more flexible than those applied in main-line railway practice. The lower limits of this relaxation of standards are easy to identify: hand-pushed rail trolleys are still used for industrial purposes. But it is hardly realistic to define the upper limit because the margin between railway and tramway is quite unclear. Underground railways in this country and in the United States are clearly a lighter form than the main-line railway, but how can one classify the 'Stadtbahn' in Wien (Vienna), which operates trains of coupled tramcars on underground railway track? For the present we shall leave the upper limit intentionally vague because - as we shall see later - there are many shades of 'heaviness' in modern tramway practice.

The Light Railway Transport League was formed in 1937 to advocate modernisation of existing tramways in this country. Although it did not succeed in this purpose, it has continued to provide an interchange of information, mainly through its magazine 'Modern Tramway' on developments abroad. The bias toward 'heavy' railway practice in recent years has brought more professionals from different transport disciplines into the LRTL, and we believe we can contribute something to the new transport technology.



Düsseldorf
FENCED SURFACE TRACK
IN CENTRAL AREA



Essen
MEDIAN STRIP SUBURBAN STATION
IN FOREGROUND. NOTE REVERSING SIDING.



CHARLOTTENPLATZ
TRAM SUBWAY STATION

Stuttgart



SOME RECENT EXAMPLES
IN WESTERN GERMANY

The new tramway fills the gap in modern transport practice between the bus system and the classical electric railway. We believe that we are on sure ground in advocating the tramway principle, but before expounding upon this subject, we must make it clear what we do not advocate: we do not seriously suggest for example, that any former tramway in this country (apart from some isolated features) exemplifies the kind of transport service relevant to future planning.

In fairness to the tramway, it should be explained that it was barely given a chance in this country. The parochial and narrow-sighted attitude of Local Authority operators, and the bad relations which almost always existed between the Authorities and the over-capitalised private operators meant that few systems were able to keep up with technological developments in the 1930's, while most were already obsolete by the 1920's. Another handicap was the restrictive legislation which made the building and working of a tramway an enormously complicated procedure.

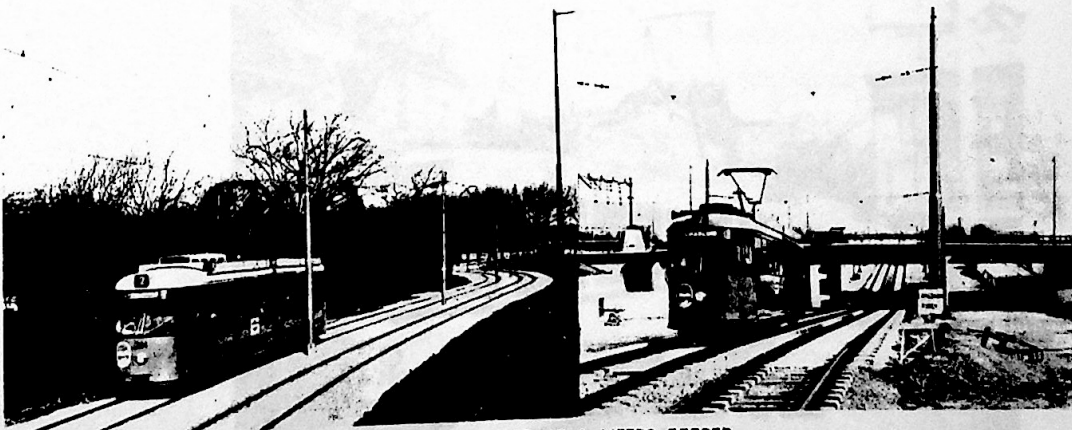
To those who doubt the merits of a modern tramway, one must unfortunately say: "Forget 99 per cent of what you have seen or heard of British trams!". Yet a great deal of credit is due to many British operators for the way in which they overcame or circumnavigated their restrictions. To give this view a correct perspective, it should be added that modern bus operation is hardly better, while suburban railway services are grudgingly operated by bodies whose contradictory terms of reference (legislated or implied) still virtually prevent any effective co-operation with local authorities or other operators to satisfy a public need. Meanwhile the private car is proving itself too demanding in space and public outlay to be allowed to develop much further.

In this context, our notion of a modern tramway has acquired a new status. Although a compromise between the bus and train as we know them, the tram can be an alternative to both and to such experimental forms as the monorail, guided hovercraft and other guided vehicle systems. The tram becomes a respectable and serious competitor in the field, offering several points in its favour:

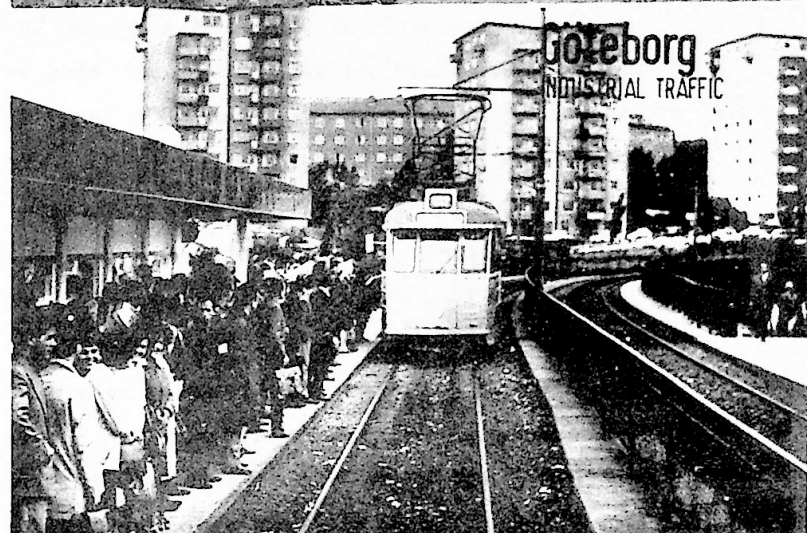
- 1 Greater technical efficiency than rubber-tyred vehicles and lower manpower demand.
- 2 Speeds and capacities comparable with conventional electric railways at lower cost where peak demand does not exceed about 22000 passengers per hour per direction.

- 3 Flexibility permitting relatively cheap alteration or 'up-grading' to heavier railway standards if later demand justifies this.
- 4 Possibility of denser network because of lower construction cost.
- 5 Adaptability to operate over sharp curves and steep inclines.
- 6 Considerable technical precedent to prove its feasibility and to indicate that further development is practicable.

Most tramway systems which exist today have many of the characteristics which we advocate. Almost all of them are a continuous development from their earlier days, and the degree to which they are free from their historical restraints varies according to the foresight of their management. Progressive undertakings today have firm plans for future development which will bring their trams closer to the popular concept of an underground railway - at least as far as central areas are concerned. Heavy construction with vertical or horizontal segregation from other traffic, using efficient high-capacity tramcars, is common practice in Central and Western Europe. We shall discuss some examples of existing systems later, but our present concern is the development of transport installations de novo, free from traditional restraints such as track and clearance gauges and axle loadings. Such schemes have been considered in recent years in this country, the USA and in Japan, but the general trend has been to concentrate on traditional underground railways which demand higher traffic densities and accordingly cannot offer the degree of accessibility available with a denser network. One can criticise the current Liverpool and Manchester schemes for relying on 'heavy' rail service plus feeder buses, which may in some cases provide a service hardly better than trams did 40 years ago.



ROTTERDAM: EXPRESS TRAM ROUTE 2, OPENED FEBRUARY 1968 AS A METRO FEEDER



2 TRAMWAY TECHNOLOGY

2.1 The Modern Tramcar

We have already described the modern tramcar as something between a bus and a train. The mechanical versatility of the bus can be combined with the efficiency of the railway. Acceleration and braking can be better than that of both train and bus, while running speeds are comparable. The fixed track makes it possible to couple any number of powered and trailing vehicles together and work them as a single train, with or without a driver.

In the past 40 years, many types of tramcar have been developed abroad to suit various operating methods, and matters such as the mode of fare collection can have a major influence upon vehicle design. Modern techniques make it possible to dispense with the conductor, the driver or both, but it may be an unnecessarily bold step to abolish both on a train carrying well over 300 passengers. Driverless control is applicable to any totally-segregated guided vehicle system and is being developed for underground railway purposes in London, Moscow and Barcelona at the present time. Conductorless operation is a simpler matter involving less technical ingenuity but calling for a review of traditional commercial principles and labour relations which has scarcely been attempted in this country although it has proved itself abroad.

Double-deck vehicles have no advantage over single-deckers where street space is not at a premium; moreover they are slow to load and involve heavier maintenance to track and vehicle. It is perhaps significant that only 13 per cent of the buses produced in the United Kingdom during 1965 were double-deckers.

Apart from technical developments in motor and transmission design the major motive in tramcar design in the last 40 years has been the need to handle the maximum number of passengers with the minimum of staff. This was the reason for the introduction of the early postwar German Grossraumwagen holding 120 passengers and the subsequent articulated cars holding up to 320 passengers attended by one conductor, and for the development in the United States in the 1930's of 100-passenger cars in which fares are collected by the driver.

A second important reason for introducing large vehicles - particularly articulated cars - has been the need to minimise vehicle deadweight. Wheels and associated running gear form a large part of the total car weight and the elimination of one bogie can bring an effective reduction in vehicle weight per passenger.

The table below indicates how the Rheinbahn in Düsseldorf has progressively reduced train deadweight by developing articulated cars in the last ten years.

	Car Type	Passenger Capacity	Unladen Weight (Tonnes)	Specific Weight (Tonnes/Passr.)
1	4-axle motor car	119	17.6	0.148
2	4-axle trailer car	145	15.4	0.106
3	1 + 2 coupled	264	33.0	0.125
4	6-axle articulated car	186	20.2	0.115
5	8-axle articulated car	256	25.4	0.099

The latest methods of conductorless operation do not always favour the articulated car which can be expensive to operate outside peak hours.

While the tendency towards longer vehicles has been apparent for 40 years, revolutionary developments in railway vehicle suspension now being tested by the British Railways Engineering Research Laboratories may well herald a return to smaller vehicles with a wheel under each corner. Such cars could be coupled to form trains of easily-variable length, or they could run singly at frequent intervals. This arrangement would lend itself to or even require driverless operation.

It is remarkable that in Britain we resent the notion that bus passengers should stand at peak hours when underground and suburban railway commuters sometimes expect to stand for journeys lasting one hour. The same criticism applies to the current American transit schemes, where a seat for every passenger is considered necessary to attract motorists out of their cars. In the case of the BART project for San Francisco, 12-car trains are envisaged; presumably the last passenger to board is expected to walk through 12 cars if necessary to find his seat!

A choice has to be made between the 93 per cent seating facility of the London RM bus and the meagre 9 per cent of recent trams in Budapest. Our observation of European practice suggests that a proportion of about 33 per cent is a minimum, except for vehicles used at peak periods only. This seating proportion is found on London tube trains, which we would regard as acceptable where most journeys last less than 20 minutes.

In order to minimise stopping time and to make loading easier and safer, it is suggested that loading platforms the height of the car floor are provided at every stop, eliminating the need for steps.

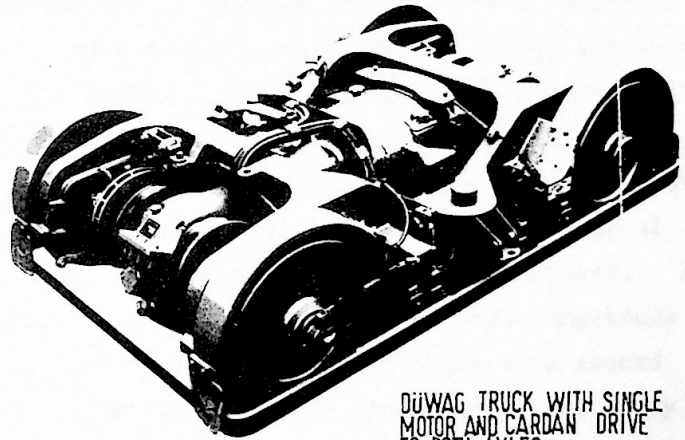
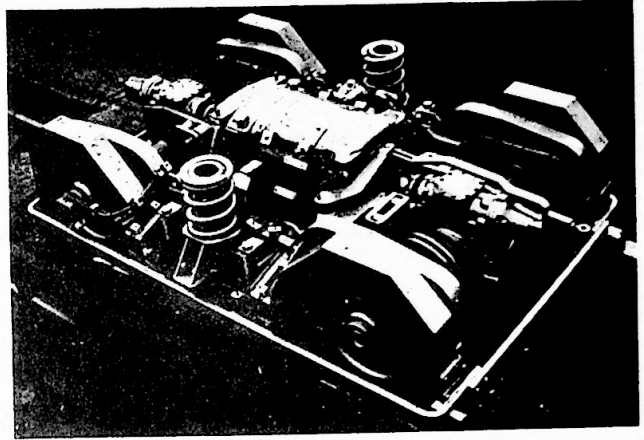
2.2 Electric Traction

We would advocate electric traction as the most efficient and convenient system for several reasons. The classical electric motor is as yet the most civilised means of motive power and its development is by no means complete. The direct-current motor was the first to be used for traction purposes in 1879 and has continued to be favoured because of its adaptability to different speed or load requirements. The first trams had a single, rather primitive, motor - in fact a reversed dynamo - and speed was controlled by connecting water or wire resistors in series with the motor. If the wire resistors were not to burn out prematurely, the motor could only be driven at full power for a short time. The development of smaller motors used in pairs soon followed, and this enabled the motors to be connected in series or in parallel, giving two continuous running speeds. A subsequent development was the device of field weakening by switching out a portion of the field windings of the motors. This technique was never favoured for tramways in this country but it is common practice abroad and is now used for electric trains here.

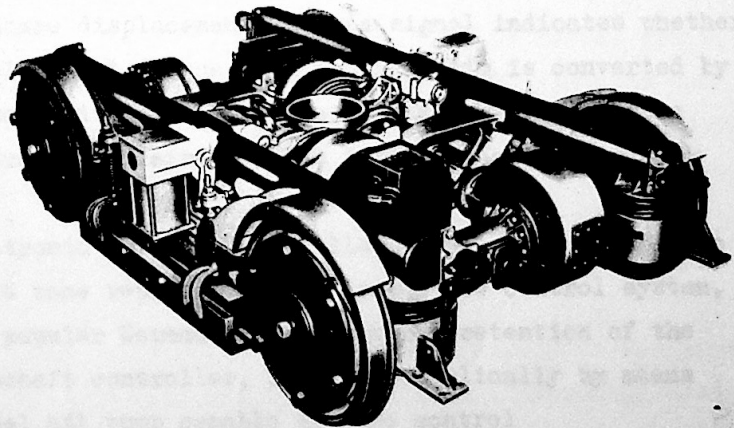
Part of the development of these systems was naturally the introduction of more intermediate 'notches' or resistor stages. This reduced the severity of the steps and permitted faster acceleration with less strain upon the motors and resistors. Regular practice today is to use electromagnetic or electropneumatic contactor control, whereby 'notching-up' is carried out automatically to the full series or full parallel positions.

Some modern tramcar trucks

The Durand bogie with a 150-kW Siemens motor. The primary springing is by rubber loaded in shear, the secondary springing is the system of helical springs mounted on the downswayed main side-member. (Westwaggon)



DÜWAG TRUCK WITH SINGLE MOTOR AND CARDAN DRIVE TO BOTH AXLES



The PCC-car bogie, showing frame-mounted motors driving hypoid gears on the axles. (Clark Equipment Company)

An earlier development which originated in the United States in the 1930's was the PCC electro-mechanical system, employing a servomechanism which continuously compares the driver's command with the speed at which the car is moving and modifies the command accordingly; sending it through 100 intermediate resistance notches for acceleration and 40 notches for braking. In this system the four motors are normally connected in parallel.

In addition to some 5000 PCC cars manufactured in the United States, about 4000 units have also been produced under licence in Belgium, Italy and Czechoslovakia. The vehicles can be driven easily, efficiently and safely. For example, in Ostrava, Czechoslovakia, we have travelled on a two-car train carrying 200 passengers at 40 miles/h, driven by a girl of 18.

A further development has been made by electronic control systems, which offer a more reliable compensating action for wheel spin. The first application of electronic controls took place in Goteborg about 1957. The development work took place at the Chalmers Technical University, and its testing and proving required many patient years, during which production of a large batch of tramcars was halted until the Tramiac system had been proved. In this system, the command signal is a square wave whose amplitude is fixed by the pedal position. 180° out of phase is a second square wave signal whose amplitude is the actual value set up by the system. If the command and actual values are identical the two signals merge into a steady signal; if they are not identical then a square wave difference signal can be extracted from the combined signal, and its amplitude indicates the amount of correction required; the phase displacement of this signal indicates whether command or actual signal is the greater, and this is converted by a simple analogue-digital computer system into relay-actuation commands to produce the desired effect in the traction circuit.

Other electronic devices have followed the original Tramiac design and, while some represent a completely new control system, two of the most popular German systems involve retention of the conventional camshaft controller, driven hydraulically by means of a toothed-wheel oil pump capable of fine control (Geamatic) or by electric motors of high or low speeds (Simatic). These have the advantage that in the event of electronic component failure, the driver can insert a normal control rod and keep the vehicle in service. The Swiss have developed another variant of electronic controls (Sécheron) in which the driver can select

braking control by (a) maximum speed or (b) by retardation rate according to environment. It will be noted that the driver of such a vehicle is required to exercise discrimination unknown in tram driving of British vehicles, but the security of passengers is unsurpassed with such a control system.

All these systems have naturally been developed for direct current at 500-1000 volts, but other electrical systems with different inherent characteristics have also been developed. For example, high-voltage single phase alternating-current traction equipment has been developed for main line purposes in Britain and abroad using current from the National Grid systems at the industrial frequency. This offers great advantages in current distribution, but control systems on the vehicle are more complicated.

Assuming the traditional electric motor with a modern control system, we can now turn to the question of power supply. Present technology on what is perhaps the most attractive form of supply - - the solar cell - - is not yet sufficiently developed to offer great prospects for light railways. At the Institution of Mechanical Engineers Convention on Guided Land Transport in October 1966, K.R. Williams (Shell Research Ltd.) and B.M. Thomas (Brush Electrical Engineering Ltd.) described the fuel cell as a feasible alternative to the diesel generator on main-line locomotives, although the cost is at present too high. 10 years appears to be the earliest date for the use of fuel cells for rail traction on a commercial scale.

Battery traction has enjoyed a renaissance in recent years, mainly owing to new efficient control methods which minimise the heavy acceleration drain on the accumulators. Remarkable success has been achieved by the German Federal Railways (DB) in operating suburban services in the Dortmund area, which may have some relevance for our purposes.

The normal means of supply from a fixed external source is by overhead wire or by conductor rail. The former is normally used for economy and because the track can then be shared with other road vehicles or pedestrians where necessary, although the wire construction must be disciplined. Other methods of power conduction, such as

intermittent contacts (energised only when vehicles pass over them) and underground conduit slots have been used in the past, and might be revived with greater success using newer techniques now available.

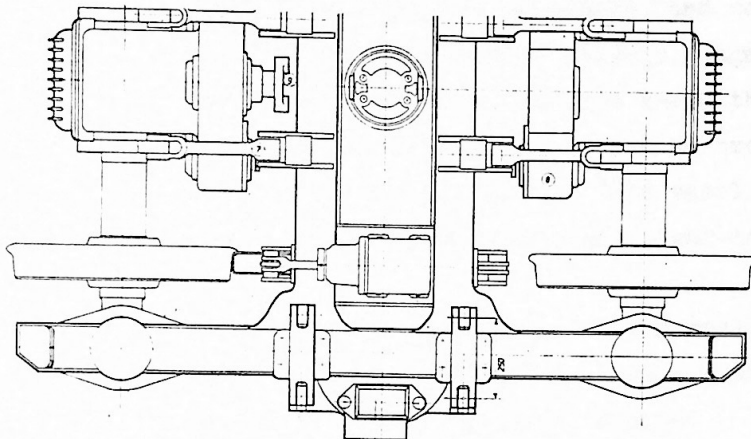
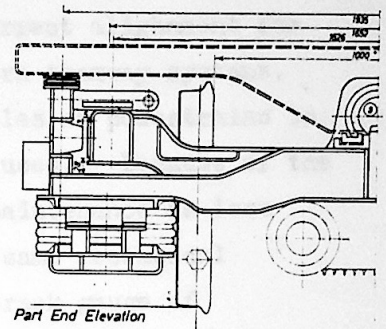
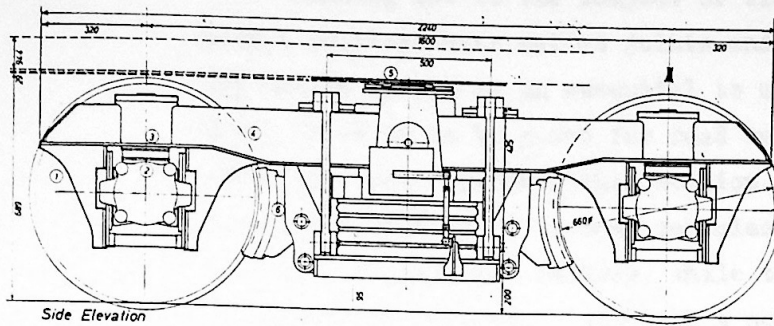
For technical reasons already discussed, rapid-transit systems today use medium-voltage direct current, and most development work has been directed in this direction. This involves expensive conversion equipment if the National Grid is to be used and frequent sub-stations and feeders along the line. Most European main-line railways -- including British Railways -- have now chosen high-voltage single-phase alternating current at the frequency of the National Grid. For tramway purposes, this system offers savings on the purchase and distribution of power although traction control development has been neglected in this field. No doubt, railway manufacturers would be able to use their expertise if called for.

There are indications that new systems of electric traction will be developed in future, such as propulsion along a linear induction field. Model experiments by a member of the Light Railway Transport League, Mr. J. P. Edgar, who is a joint patentee of a principle of dc linear induction motive power, show a remarkable performance, but control of the acceleration within tolerable limits for passenger comfort and safety will require intensive research.

2.3 Alternative Traction Forms

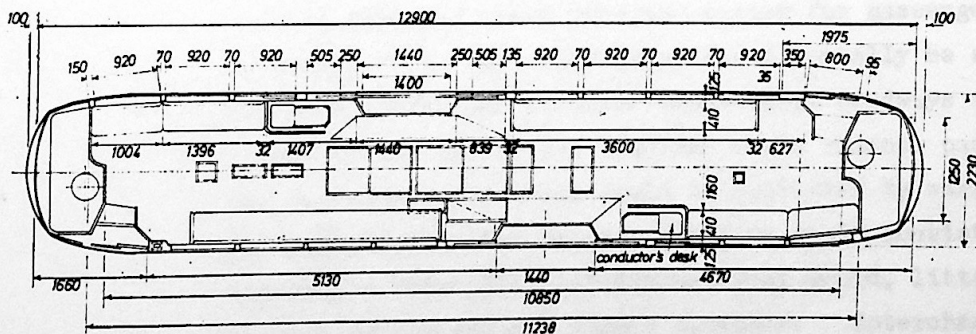
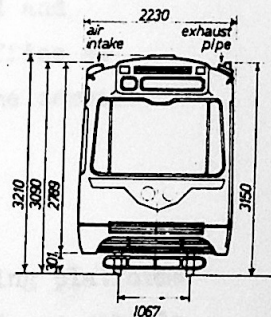
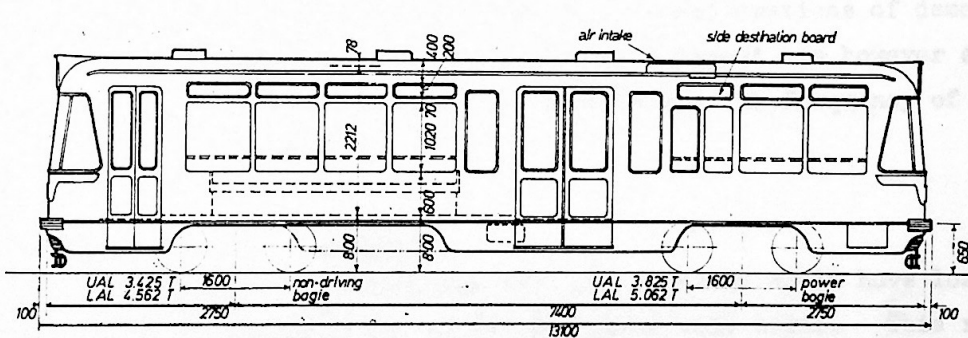
Oil or gas fuel is probably the only alternative to electricity, and on many scores it is only a second-best. A remarkable example of diesel tram operation was on the Sapporo Municipal Tramways in Japan, which for a few years operated diesel trams on some new routes which have since been electrified. The mechanical components bore a similarity to British Railways diesel trains which was obviously no accident. The trams were capable of multiple-unit operation in the same way as their main-line counterparts in Britain. They are now being converted for electric working.

The other possible use of oil fuel is for the gas-turbine system. Renewed interest is being shown in this method of propulsion by main-line railways in the United States and Britain, but there appears to be little application of the principle for short-distance traffic, where continuous high speeds are not required.



- ① WHEEL AND AXLE
- ② BEARING BOX
- ③ SPRINGING
- ④ TRUCK FRAME
- ⑤ BOLSTER
- ⑥ BRAKE GEAR
- ⑦ REDUCTION GEAR HANGER
- ⑧ POWER TRANSMISSION
- ⑨ PROPELLER SHAFT

Redrawn from official drawing
All dimensions in millimetres



UAL: unladen axle load
LAL: laden axle load

unladen weight 4.5 tonnes

seat capacity 30
standing capacity 60
total capacity 90

wheel diameter 680

redrawn from official dwg.

Sapporo Municipal Tramways (Japan)

Diesel Car Class D1040

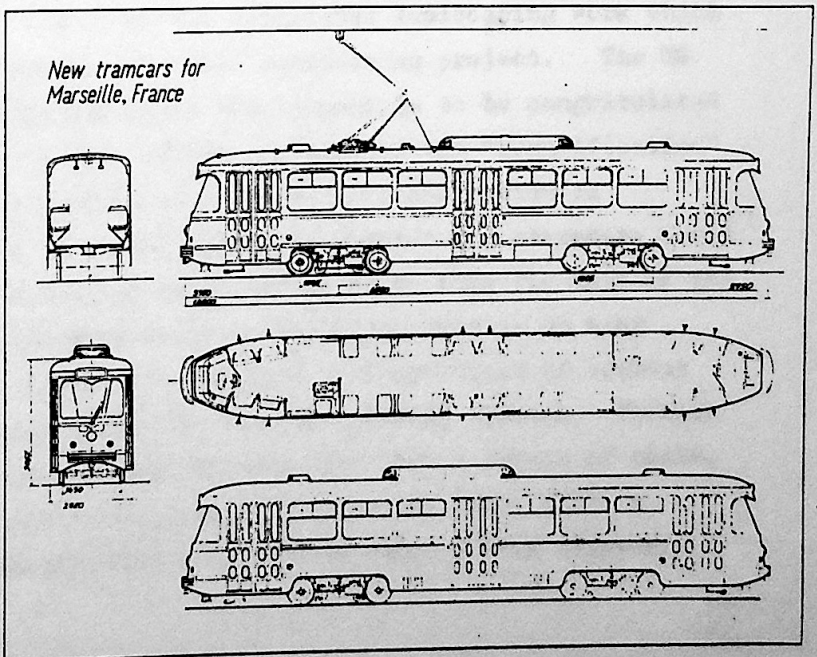
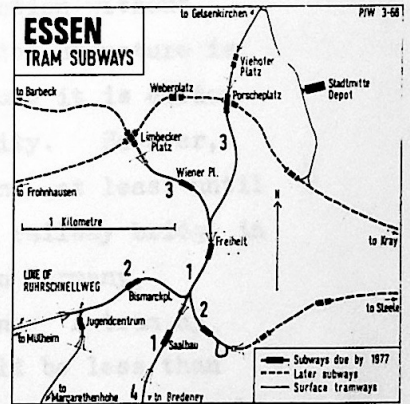
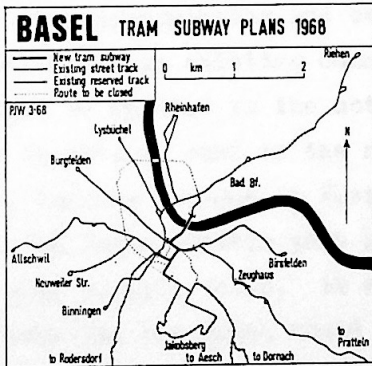
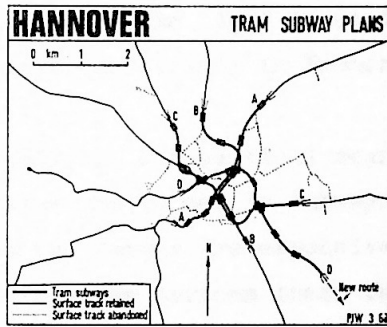
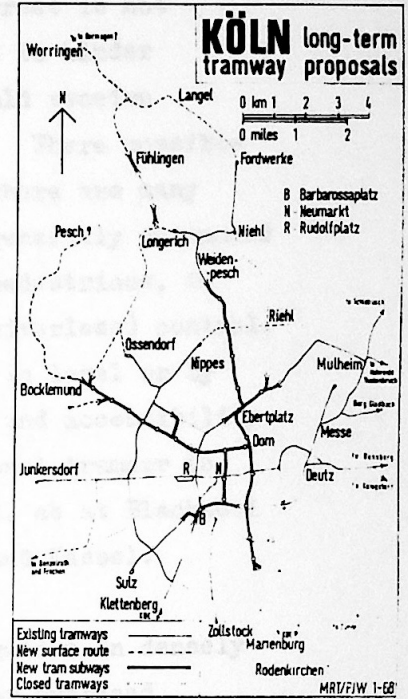
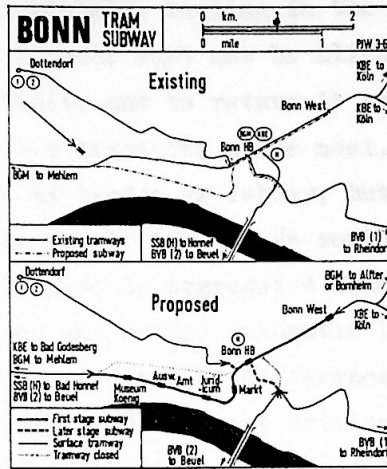
2.4 Tramway Track

Turning now to the subject of track, the kind found on modern railways with welded joints and correct alignment for the design speeds is an essential to modern tramway systems. Where track is to be paved for road vehicles or pedestrians to share the route, grooved rail section is used. Because of the relative lightness of tramway vehicles, maintenance is less than on a traditional railway, while the same mechanical equipment can be used. Although a new track gauge of 1696 mm (5'-6") was selected for the BART project, its advantages appear to be slight, and we would recommend the adoption of the standard railway gauge of 1435 mm (4'-8 $\frac{1}{2}$ ") to make use of existing products where these are available. A variety of surfaces can be provided between and around the rails: these can vary from steel plate to lawns, according to the other functions of the right-of-way.

While double track would normally be selected, a saving could be made by providing a single track where there is no possibility of a frequent service. The disadvantages of the system are obvious, the principal one being the difficulty of maintaining an adequate service without an automatic control system which would override considerations of demand and convenience. A single-track layout can however suffice at the extremities of a route where the frequency of the service is reduced.

2.5 Stations

We envisage that all stations would have loading platforms at about 800 mm (2'-8") above rail level. This reduces vehicle waiting time and makes boarding easier for passengers. In the interests of safety, passengers would normally be segregated from the tram track, but at outer stops where headways are greater, a ramp at the end of the platform would channel passengers to one crossing point which could be protected by warning signals. The furniture on the station platform would consist of an awning, benches, a timetable, illuminated name-board, litter bins and if part of the system, ticket machines. Interchange stations between two routes should be on two levels with direct escalator connexion between platforms. External considerations will probably favour busy stations being sited above or below ground level. Separate entrances and exits (at least for rush-hour traffic) can facilitate passenger circulation and simplify fare collection.

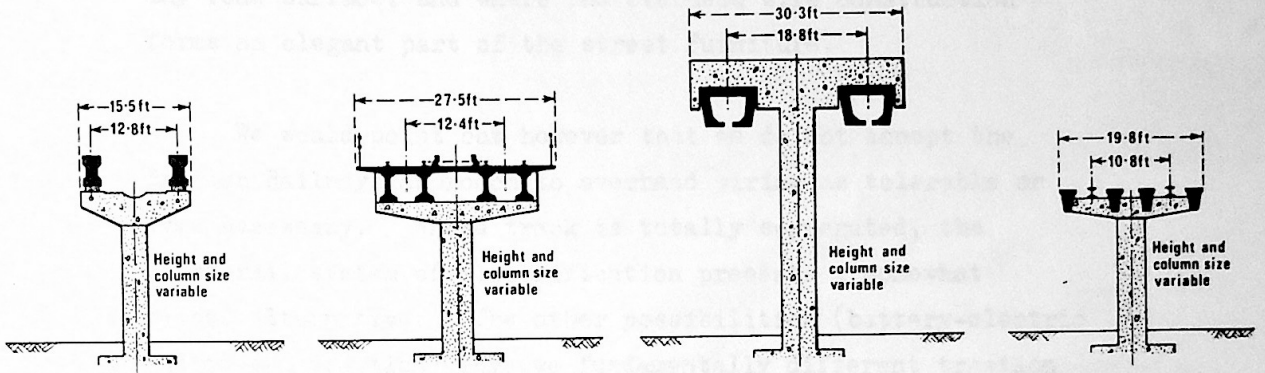


2.6 Segregation

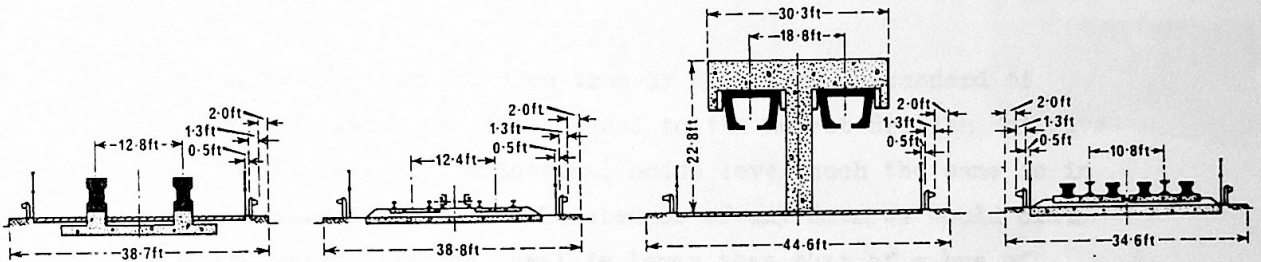
As implied previously, loading in the street is not recommended. The tramcar must not be allowed to hinder road traffic by default, and in return it should receive priority where the two transport modes meet. Where possible crossings should be by bridge or subway, but there are many instances where this is too dear. We would generally recommend that tramways should also be segregated from pedestrians, to allow for high speeds and future automatic (driverless) control. The separation can be effected by differences in level or by fencing. Where high speeds are not critical and accessibility is most important, the ability of the traditional tramcar to mingle with pedestrian traffic might be useful, as at Blackpool Promenade or in pedestrian streets in Bremen and Kassel.

There is a good case for vertical segregation in densely developed areas, which can be met by subways or overhead structures. While the former are expensive and not particularly pleasant to travel in, they perform their function without disturbing the environment above. The elevated structure is perhaps more attractive economically and because it is easier and quicker to complete in an existing community. However, popular opinion might be opposed to the notion - at least until examples of modern structures such as the new railway bridge in Delft, Holland, and tramway bridges in Western Germany, Czechoslovakia and the United States were seen. A tramway viaduct would not need parapet walls; it would be less than 6 metres (20'-0") wide and the depth would be determined purely by structural considerations. What is possibly more important than the structure itself is the associated landscaping work which should rightly accompany any civil engineering project. The US Department of Housing and Urban Development is to be congratulated for making a grant of some £70000 per mile to the "beautification" of the terrain of 2.7 miles of the BART elevated system in San Francisco. It is indeed debatable whether the structure would in fact be more detrimental to the urban scene than the bulk of the monorail tracks which have until recently appeared in so many sketches; Diagram 1 indicates typical cross-sections of tramway construction in comparison with the two monorail systems. Whereas in the past elevated railways brought with them a horror of noise, there is every reason to suppose that the noise level below a modern tramway viaduct would be less than under a road flyover.

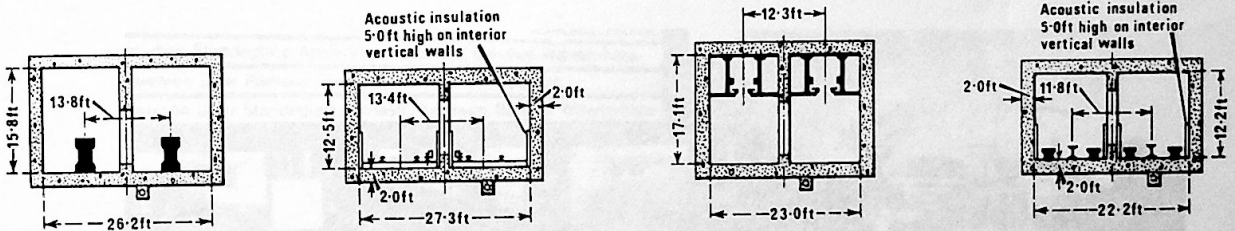
Diagram 1



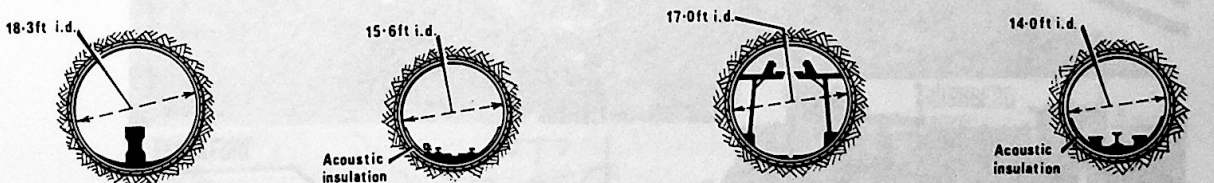
ELEVATED STRUCTURES



GROUND LEVEL IN MEDIAN STRIP



CUT AND COVER



TUNNEL

ALWEG

DUORAIL

SAFEGE

WESTINGHOUSE

COMPARISON OF TRACK STRUCTURES

Reproduced by kind permission of the Editor, 'Railway Gazette'

2.7 Environment

Many overseas examples can be quoted where public areas served by tram are paved in a manner far more pleasing than any road surface, and where the overhead wire construction forms an elegant part of the street furniture.

We would point out however that we do not accept the British Railways approach to overhead wiring as tolerable or even necessary. Where track is totally segregated, the third-rail system of electrification presents a somewhat dearer alternative. The other possibilities (battery-electric and diesel traction) involve fundamentally different traction systems which need special investigation because they have not been adequately developed.

A well-designed modern tramway can offer a standard of comfort and riding qualities equal to the newest British Railways coaching stock, with an internal noise level much the same as in a larger saloon car. In the absence of any data, we would claim that the external noise level is lower than that of a bus of much lower capacity. There are, however no smells of oil or exhaust gases.



EXAMPLES OF HORIZONTAL AND VERTICAL SEGREGATION



Bern
TRAM SUBWAY



München
FENCED SURFACE TRACK
IN OUTER SUBURBS



3 TRAMWAY OPERATION

3.1 Capacities

Before considering the planning of tramways even in principle, we should discuss the basic characteristics of capacity, speed and frequency.

Unlike the traditional British tramway which employed small cars, each carrying two employees, modern methods enable 350 passengers or more to be hauled quickly and safely, by a three-car tram train staffed only by a driver. Where demand justifies a peak headway of 50 seconds, this implies a crush capacity of 22000 passengers per hour (instead of 350 London buses or about 20000 private cars.)

Loadings beyond this level are more efficiently handled by 'heavy' railways, but the true demand could sometimes be served better by two parallel routes of lower capacity. In other words, two parallel tramway routes with a capacity of, say 20 000 passengers per hour per direction could satisfy passenger demand better than one railway route with a capacity of 40-50 000 passengers per hour per direction, quite apart from the problem of feeder services. There are however examples of tramway routes carrying phenomenal loads; for instance, tram trains running along the wide Ring in Budapest regularly coped with peak loads of 32 000 passengers per hour while the new Elizabeth Bridge was being built.

We have dealt with the upper physical limits of tramway capacity, but the lower limit is an economic one which will be discussed later.

3.2 Speeds and Frequencies

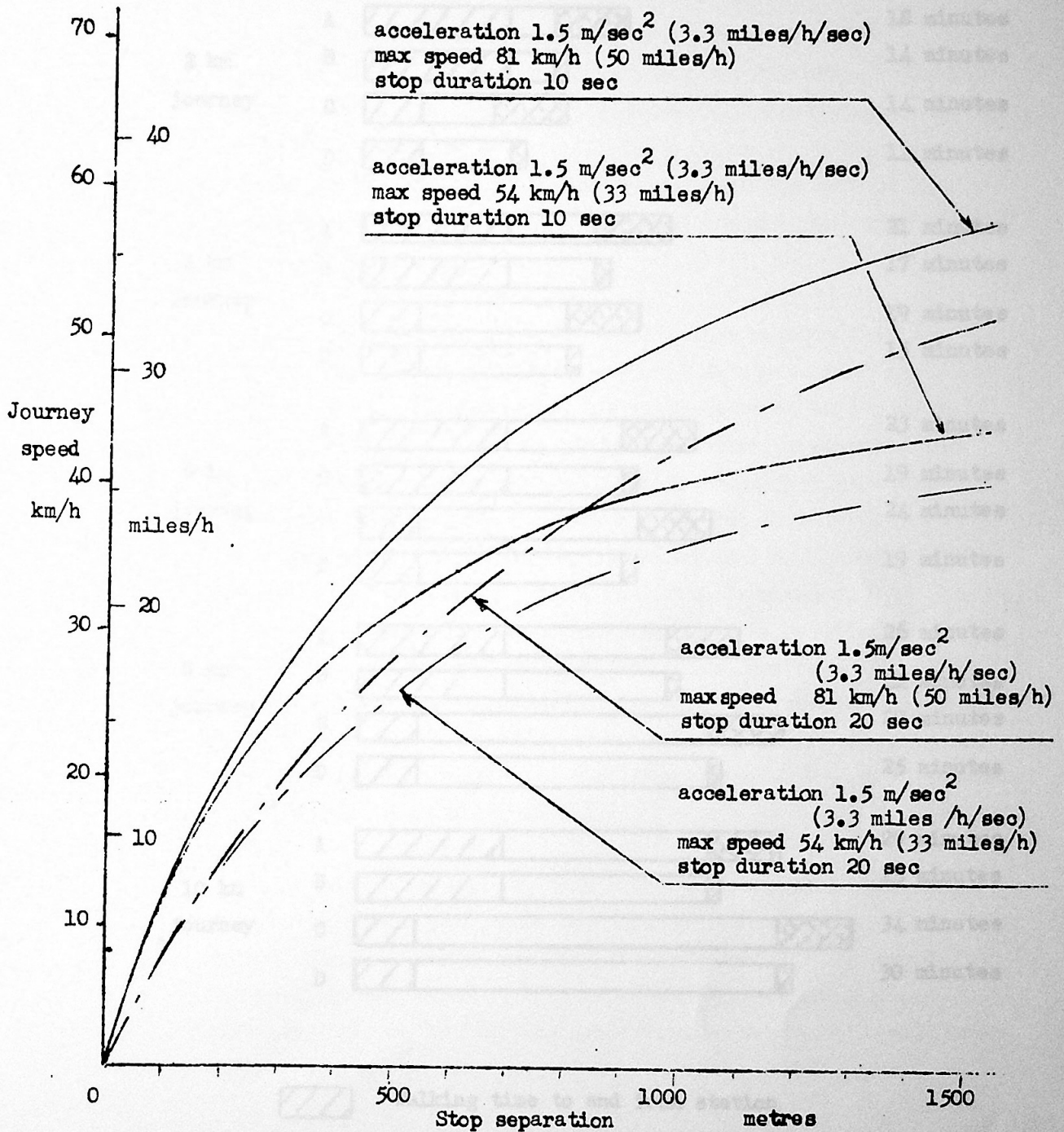
The good adhesion characteristics between steel wheels and rails have already been mentioned, and this must be stressed because of popular misconceptions about the superiority of rubber-tyred vehicles in this respect. Many tramcars have been built which are claimed to have acceleration parameters of 2.0 m/sec^2 (4.4 mile/h/sec). For our purposes, assuming that stops due to traffic congestion are eliminated because of segregated right-of-way, we would suggest a lower rate of 1.3 m/sec^2 (2.8 mile/h/sec) for modern requirements because of the substantial saving in maximum power demand and the weight of equipment carried. This contrasts, incidentally, with an acceleration rate of 0.68 m/sec^2 (1.5 mile/h/sec) on existing tube trains in London. Maximum running speeds of

81 km/h (50 mile/h) are common practice today, but this is not possible where stops are frequent. Journey speeds, which are illustrated in diagram 2, are a function of the parameters of acceleration, maximum speed (not invariably), stop separation and stop duration. Stop separation is mainly a commercial or social consideration which will be considered more fully later. Stop duration is an important factor in journey speeds, and it is obviously most important to keep this to a minimum. Using loading platforms and power-operated doors, stopping time will vary, probably between 10 and 20 seconds, according to the importance of each stop.

To compete with private transport, and to obtain a realistic view of the true travelling time to the passenger, the door-to-door journey times should be considered. Diagram 3 indicates the value of a relatively slow service with frequent stops and a low headway, particularly on shorter journeys. Where reliable running to a simple timetable can be guaranteed, the case against wide headways is of course weaker, because regular travellers will time their journey to minimise the waiting period.

3.3 Fares

The method of payment by the passenger deserves some attention, mainly because it is a subject which has been almost totally neglected in this country for thirty years. The first question one should ask is why charge fares? If we regard transportation as an urban public service there is a good case for the costs being borne by local authority rates. To our knowledge, studies have been carried out recently by two authorities in this country. The Bucks County Architect considered this system of charging for the monorail project for the new town at Bletchley, calculating that a levy of about 7s. 6d per household per week would cover the costs of operation, while more recently, the former General Manager of Sunderland Corporation Transport Department arrived at a mean figure of about 3s. 6d per head of the population to operate the existing services with a provision for a 25% increase in demand. Both figures are of course hypothetical, but they do suggest a considerable saving over present costs to the passenger (which is to be expected because of simpler operation involved), while providing a powerful incentive to the private motorist to use public transport for those journeys which would otherwise hinder other road users. This philosophy is in keeping with modern Swiss thought, which favours the costs of tramway and light railway improvements being paid for by the motorist, whose



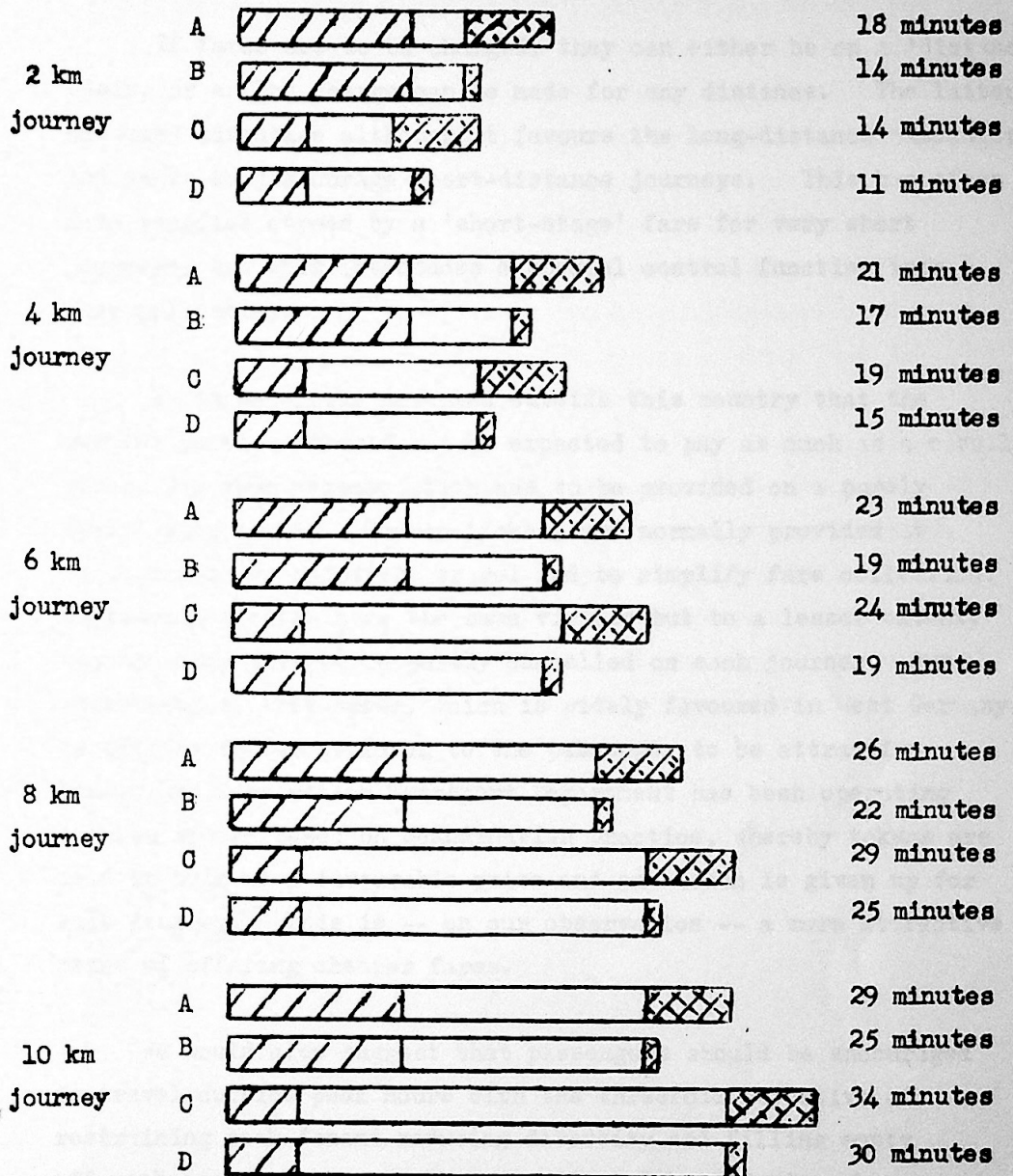
Mathematical model

$$\text{Journey speed} = \frac{1}{\frac{1}{v} + \left(\frac{v}{a} + t_s \right) n}$$

where v = maximum velocity
 a = acceleration / deceleration
 t_s = stop duration
 n = number of stops

RELATIONSHIP OF JOURNEY SPEED TO STOP SPACING AND DURATION, MAXIMUM SPEED,
AND RATE OF ACCELERATION / BRAKING

Source : W.J.Wyse & Author.



 Walking time to and from station
 Travelling time
 Waiting time

A	System with 1000m stop separation, 10 minute headway							
B	"	"	"	"	"	2	"	"
C	"	"	400m	"	"	10	"	"
D	"	"	"	"	"	2	"	"

COMPARATIVE MEAN DOOR-TO-DOOR JOURNEY TIMES

Effect of stop separation and service headway

Source : Author.

whose activities have necessitated the improvements.

If fares are to be charged, they can either be on a 'distance' basis, or a flat charge can be made for any distance. The latter has many advantage although it favours the long-distance passenger, and tends to discourage short-distance journeys. This has often been remedied abroad by a 'short-stage' fare for very short journeys, but this introduces a special control function into fare collection.

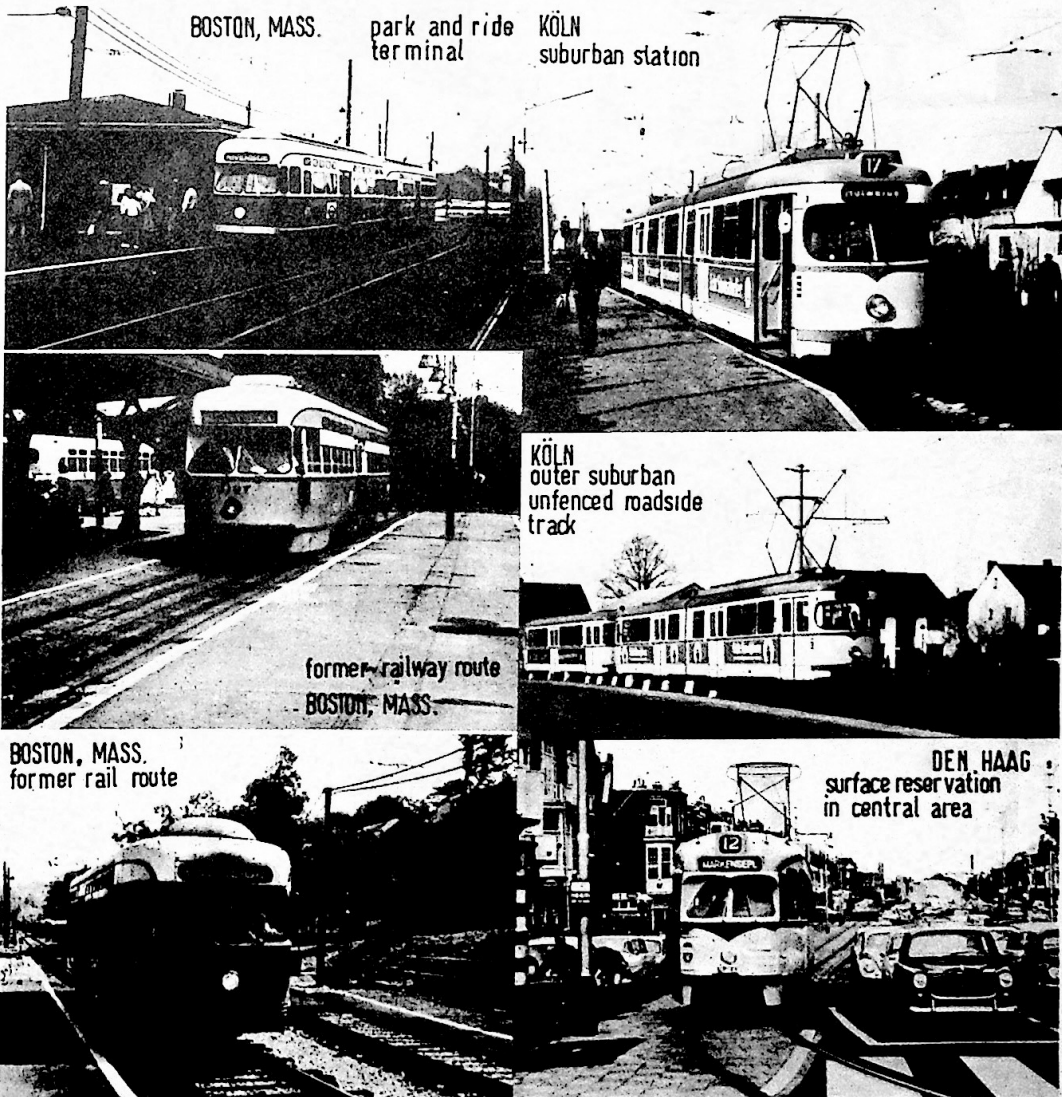
It is generally accepted outside this country that the regular customer should not be expected to pay as much as a casual rider, for whom accommodation has to be provided on a purely speculative basis. Season tickets are normally provided at a reduced rate to encourage travel and to simplify fare collection. Multi-ride tickets have the same virtues but to a lesser extent, because they have to be partly cancelled on each journey. Our experience of this system, which is widely favoured in West Germany, is that it is too confusing to the passenger to be attractive. Sunderland Corporation Transport Department has been operating a token system based on Scandinavian practice, whereby tokens are sold in bulk at a favourable price and one token is given up for each journey. This is -- on our observation -- a more attractive means of offering cheaper fares.

We would also suggest that passengers should be encouraged to travel outside peak hours with the threefold objective of restraining peak demand, reducing diversity and filling empty off-peak accommodation. This is effected by offering cheap off-peak fares or by limiting concession tickets to off-peak hours only.

Methods of fare collection on the vehicle deserve attention because of the effect they have upon the manpower required to operate a service. As labour represents an important part of operating costs (usually over 70% on English bus systems) and it is generally difficult to recruit, any means of reducing manpower is very desirable. The traditional method of fare collection, whereby a roving conductor collects as many fares as he can, is extravagant. For 40 years, foreign undertakings have either given the conductor a fixed desk, from which he (or she) collects fares from passengers as they pass, or the driver has collected fares from passengers

as they enter or leave. The one-man system has saved many lightly-loaded routes from higher fares or abandonment, but journey speeds tended to decline because of the longer wait at stops. The American planner, Victor Gruen, has made an eloquent plea for the return to two-man operation in his book "The Heart of the City", but we doubt whether this has any commercial or even social justification. Recent European practice relies upon passengers using self-service ticket-cancelling machines on the car, subject to increased random checks by inspectors, authorised to charge a penal fare to defaulters.

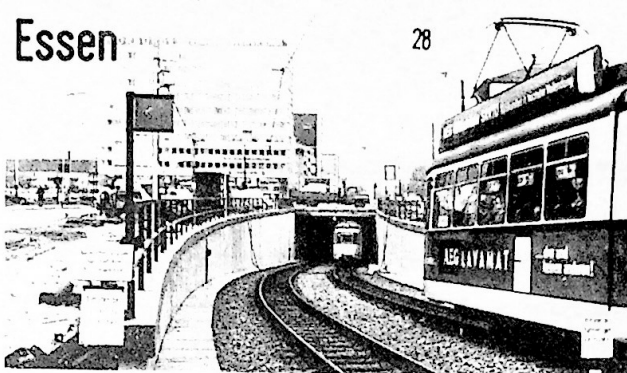
Fare collection off the car presents many advantages, and even if we discount the notion of a manned booking office at each station or stopping-place, there is the possibility of automatic machines to 'validate' blank tickets, possibly sold in bulk at kiosks or by nearby tobacconists or confectioners at a discount. This practice is becoming popular on the European Continent.



Essen

28

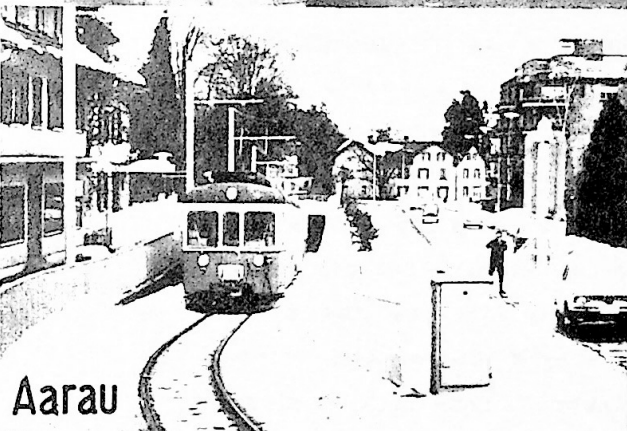
Kassel



Essen

'TRAM-ONLY' SHOPPING STREET

Kassel



Aarau



Dortmund

Bern



Košice



Bern



Košice

4 GENERAL PLANNING CONSIDERATIONS

Now that we have discussed various aspects of tramway operation in some detail, we can consider the general characteristics of a tramway system. The objectives of any public transport installation are to attract and to serve as much traffic as possible. This dictates a route pattern directly between the traffic centres, the location of which is in the hands of planners, both in the case of new towns and of existing urban areas to be renewed. It is desirable that a decision should be taken on the precise mode of public transport as early as possible because each mode has its own characteristics which should be used to their full advantage in later planning.

While all fixed-track transport installations require a relatively high population density to succeed financially, the modern tramway is at an advantage over the underground railway because of the lower construction costs which permit a denser network -- reducing the distance between routes and if possible, eliminating the need for feeder services and the delay due to transfers. The cost of tramway construction diminishes in lighter populated areas as the degree of segregation from other traffic reduces, with a corresponding simplification of engineering works. One can envisage a system of tram subways or elevated ways in central areas; reservations -- probably with embankments, cuttings and bridges -- in medium-density areas; and surface construction, perhaps with some level crossings or even street track in outer districts. There would be inevitable exceptions: for example, it may be proper for trams to run on the surface through a shopping precinct. This has been done at Bremen, Kassel and Magdeburg in Germany and a similar proposal has been made for the Chestnut Street Shopping mall in Philadelphia, USA.

We have already discussed the question of speeds, from which we can expect a mean commercial speed of 20-30 km/h (12.5-18.75 mile/h). In Czechoslovakia a maximum travelling time by any public service vehicle of 20 minutes has been suggested, and this gives a useful indication of the required commercial speed for any instance, and it implies a maximum commuting distance of 7-10 km ($4\frac{1}{2}$ - 6 miles) beyond which the tramway would cease to be attractive. Longer routes would probably be found only in larger cities with sufficient densities and means to justify 'heavy' electric railways

on trunk routes. However, we can repeat our earlier assertion that a tramway can be constructed in such a way that it can be subsequently 'up-graded' to heavy railway standards when traffic has been developed.

Most existing towns have a predominantly radial pattern of public transport with lighter tangential flows which often apply only at peak hours. Many of the social disadvantages of this pattern have been avoided in the planning of new towns in which the development is linear (or to be more correct, curvilinear as the line is often bent to form a loop). The fundamental of a linear development is that there is only one two-way basic communications route. Such an arrangement favours the fixed-track system, and where the peak traffic demand does not exceed 22000 passengers per hour within the next 10 years, we would suggest that the modern tramway can provide the ideal answer.

The relatively high costs of construction can in some cases be lessened by the incorporation of an abandoned railway or canal route, and this short-term saving could well affect the planning of a new town. Similarly, a tramway running next to an existing railway or to a new road would be cheaper to build; but whereas a road should not necessarily run direct from traffic centre to centre, it is essential that the public transport system serves these focal points, by branching from the other route if necessary. There are many existing towns where ill-used railway tracks could be converted into a first-class rapid tramway. We have been involved in such projects for Birmingham, Manchester, Leeds and Belfast, and it is certain there is a potential here which -- although not so glamorous as a system in a new town -- could virtually solve these cities' transport problems. For the reasons which we have already mentioned, we would venture to claim that our solution would be more effective than such American schemes as the BART project at San Francisco.

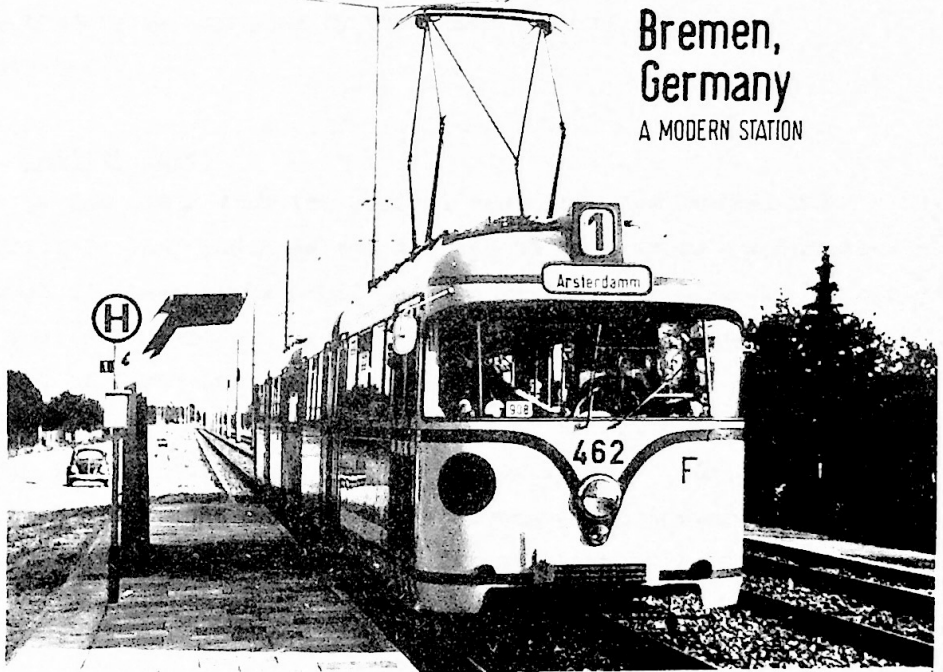
Sapporo, Japan

NEW ROLLING STOCK



Bremen, Germany

A MODERN STATION



Rotterdam, Netherlands

INTERCHANGE STATION WITH METRO SYSTEM



FURTHER MODERN EXAMPLES

5 COSTS

We should very much like to be able to apply financial tests to our theories on the solution of urban transport problems, and we should be glad to co-operate in any studies on this matter, particularly if they could reveal the true relative costs of various transit modes including the modern tramway. Although we have good relations with manufacturers and operators in many countries, as a voluntary organisation we do not have the resources to process the data to which we have access. Comparative studies on the American pattern, such as those by Meyer Kain and Wohl, are now being applied to British conditions and these will be of value in the new science of transport, but one must have reservations about the logic of some of the basic assumptions which tends to be obscured by the sheer mass of subsequent computations.

5.1 Capital Costs

We can break down the capital cost into six components. The first is land purchase and the second is roadbed construction. The cost of these items would be more or less the same as for a new road 6 m (20') wide. In the case of new or redeveloped areas, the cost of earthworks can be shared with associated public services (roads, drains, water, etc). The use of an existing road or railway would reduce this cost to virtually nil. In densely developed areas, the cost of a new subway 4.4 m deep by 7.1 m wide (15' x 23') need not be uneconomic in relation to land value (real or potential) in that area.

The third factor is the cost of track construction, which would vary according to designed operating speeds and the degree of future maintenance envisaged. One large West German tramway system quoted costs of track construction in 1965 at DM 300 per metre of double track, or about £105 000 per mile. In some cases, a degree of signalling is required on parts of the route, involving an additional cost.

The fourth item is the cost of electric distribution equipment, which depends on the electrical system selected and the anticipated density of traffic. The cost of overhead conductor wire installation can be reckoned as ten per cent of the track cost.

The cost of the fifth item -- rolling stock -- is difficult to estimate because factory costs are necessarily related to the degree of mass-production. In West Germany it was stated in 1964 that a pair of underground cars to hold 150 passengers would cost about DM 400 000 (about £42 000) and an articulated tramcar with a similar capacity about half as much. A Czech manufacturer quoted US \$ 45 000 for the mass-produced T3 tramcar carrying up to 120 passengers. This firm states that the T3 car has a life of 1 200 000 km, requiring a major overhaul at 600 000 km which would cost \$ 23 500.

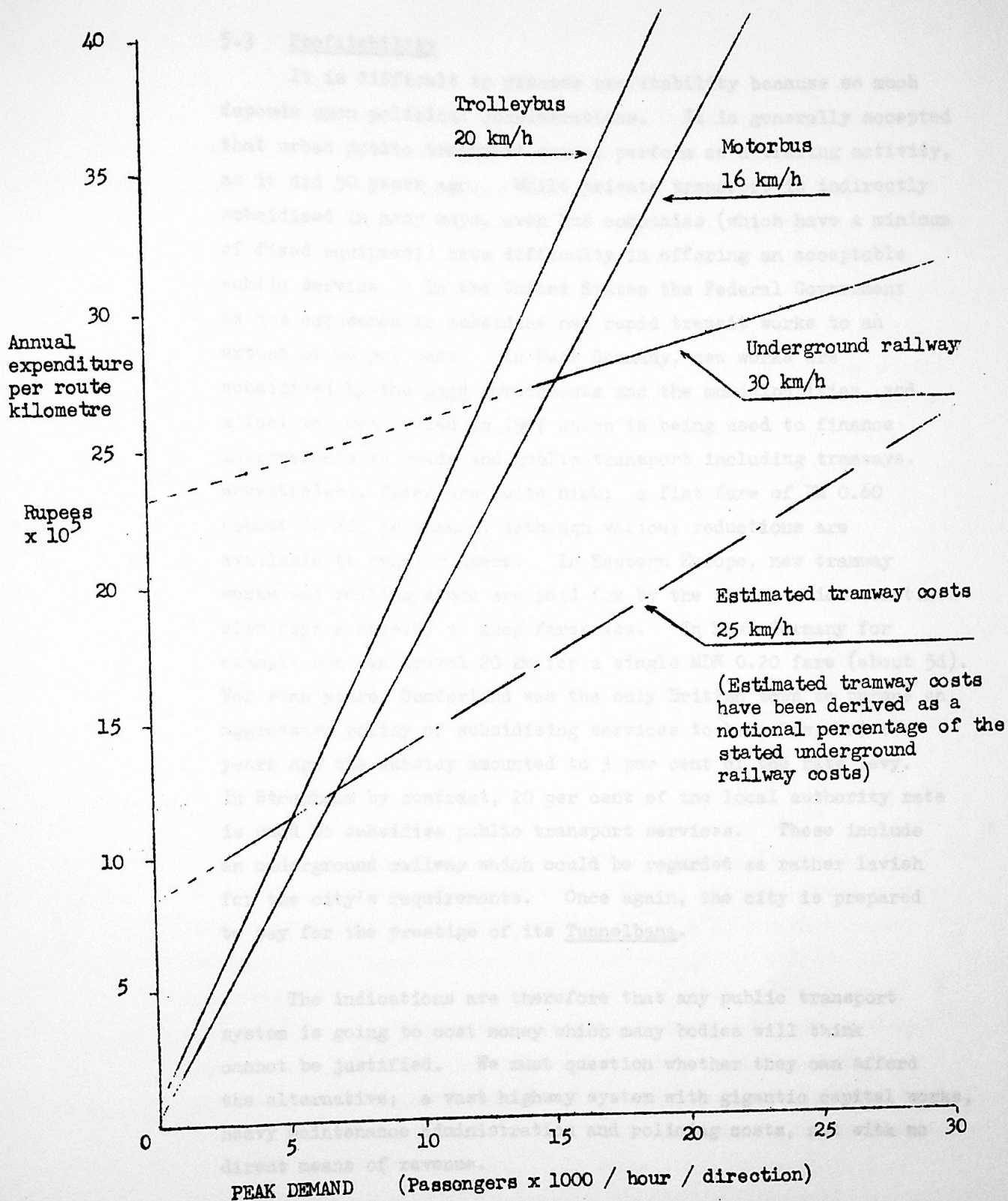
The last portion of capital costs covers buildings and ancillary equipment, comprising repair shop, cleaning equipment, administrative and staff accommodation and passenger facilities. A covered depot is generally regarded nowadays as unnecessary.

5.2 Running Costs

The general characteristic of tramway costs is something between the cost pattern of a bus service and of an electric railway service. Because of the small amount of equipment and the high staffing ratio, bus costs rise almost directly in proportion to traffic density, and there is the rather intangible cost of the public road to be taken into account. Railway costs comprise a high fixed element with a very gradual increase in relation to traffic density. With a tramway system, the extent of the fixed costs could be carefully balanced in relation to the peak traffic density. In the absence of any better material, diagram 4 shows hypothetical figures produced by the Bombay transport undertaking, on which we have superimposed a very approximate cost parameter for a tramway purely for comparative purposes.

Excluding debt charges and depreciation on fixed equipment and rolling stock, running costs will comprise maintenance of fixed assets and rolling stock, traffic staff wages, power supply and administrative overheads (which may include a form of taxation). In modern operating conditions, traffic staff wages form the major part of running costs, and any future system should therefore be designed to minimise the staffing of cars.

Diagram 4.



COMPARATIVE MODAL COSTS FOR BOMBAY

(Source : P.G.Patankar - "Future Transportation Pattern for Bombay" 1965
Tramway costs added by author)

5.3 Profitability

It is difficult to discuss profitability because so much depends upon political considerations. It is generally accepted that urban public transport cannot perform as a trading activity, as it did 50 years ago. While private transport is indirectly subsidised in many ways, even bus companies (which have a minimum of fixed equipment) have difficulty in offering an acceptable public service. In the United States the Federal Government is now empowered to subsidise new rapid transit works to an extent of 66 per cent. In West Germany, new works are subsidised by the Land governments and the municipalities, and a fuel tax was levied in 1967 which is being used to finance improvements to roads and public transport including tramways. Nevertheless, fares are quite high; a flat fare of DM 0.60 (about 1s 2d) is common, although various reductions are available to regular users. In Eastern Europe, new tramway works and rolling stock are paid for by the state, which sometimes also pays a subsidy to keep fares low. In East Germany for example one can travel 20 km for a single MDN 0.20 fare (about 5d). For some years, Sunderland was the only British town to pursue an aggressive policy of subsidising services to keep low, and two years ago the subsidy amounted to 3 per cent of the rate levy. In Stockholm by contrast, 20 per cent of the local authority rate is used to subsidise public transport services. These include an underground railway which could be regarded as rather lavish for the city's requirements. Once again, the city is prepared to pay for the prestige of its Tunnelbana.

The indications are therefore that any public transport system is going to cost money which many bodies will think cannot be justified. We must question whether they can afford the alternative; a vast highway system with gigantic capital works, heavy maintenance administration and policing costs, and with no direct means of revenue.

Even in the United States, local authority subsidies are not unknown, and Boston's outlying communities pay 10 per cent of their rate levies to the Massachusetts Bay Transportation Authority.

OTHER TRANSPORT MODES.

6.1 The Bus

We have not yet considered any of the alternative means of transportation, existing or proposed. The existing range comprises bus train and possibly monorail (insofar as some pilot projects have been constructed). When the Light Railway Transport League was formed in 1937 its main object was to arrest the replacement of trams by buses. In view of the state of some of the tramway systems at that time, it is perhaps as well that we did not succeed in our aims. Since then we have seen the decline of the bus - due to the demands of the motor car and its owner -- and we can well consider the bus as a companion in misfortune. Where peak flows do not exceed about 2 000 passengers per hour in one direction, we would accept that the bus is the proper means of transport, provided that it can be given a right of way unobstructed by other traffic. This is nowadays rarely the case, and the arbiter in any choice between a bus service and a fixed-track system will probably be the relative cost of providing a reserved bus track where necessary against the cost of a fixed-track system over the entire route. This question again involves the cost penalty for increased public transport speeds.

6.2 The Electric Railway

The position of the heavy electric railway is unassailable where high-density traffic exists. Expert opinion abroad quotes different levels of intensity as the minimum to demand a heavy railway: the figure appears to be between 20 000 and 30 000 passengers per hour in one direction. In favour of the rapid tramway, we would repeat that it offers a useful expedient where traffic is expected to increase later offering an immediate return on capital investment. A tramway can be constructed to handle initial light traffic and it can subsequently be up-graded when the demand is increased. In Bruxelles, for example, the east-west tram subway now under construction will be upgraded when the peak traffic reaches 14 000 passengers per hour.

6.3 The Monorail

The monorail principle has attracted vast publicity attention in recent years, although it is in fact as old as the conventional dual-rail concept. Enthusiasm was at its peak while various monorails were being built, but in recent months we have heard less and less about the system. In assessing the reason for the demise of the

monorail, the "Comparative Analysis of Transit Vehicle Systems" prepared for the National Capital Transportation Agency of Washington D.C., by Operations Research Inc. of Silver Spring, Maryland, makes some useful points. The analysis explains how the monorail is inferior in respect of mechanical stability, the scope for high-speed running and the risk of accident and derailment, and the virtual impossibility of operating a reliable form of turnout is stressed. The report is unable to conclude that a rubber-wheeled monorail system is superior to a well-designed dual-rail system as far as noise-emission is concerned, and states:

"Under conditions most favourable to suspended or overriding monorail systems, -- that is 100 per cent overhead structure -- they are more expensive than dual-rail systems. Under realistic conditions involving a mix of overhead, at-grade and/or below-grade rights-of-way the cost disadvantage to these systems increases."

Many of our members have been highly critical of the enthusiasm for monorails which waxed first in the United States and later in this country. Our scepticism has been borne out by the disappointments experienced by the promoters of the two different installations in Tokyo and that in Seattle. Both Alweg and Safege demonstration tracks were dismantled in 1967. The monorail has failed to establish a status beyond that of a pleasure-ground attraction in Japan and the United States, and we hope that British monorail protagonists will study their projects dispassionately and in the light of results elsewhere before committing themselves.

6.4 Rubber-Tyred Guided Systems

The Washington study considered rubber-tyred fixed-track systems and found that all technical studies so far carried out in the United States had compared these forms only with obsolete railway systems. It recommends that studies should be continued in comparison with modern railways. We have already mentioned the reversal of the Paris Metro policy, which may point to the outcome of such studies. A scheme for rubber-tyred trains was seriously considered in the 1950's for Milano, but by 1961, resilient-wheeled railway vehicles were selected, and this new underground railway was opened in 1964.

6.5 Dual-Purpose Vehicles

A transport mode which shows greater promise is the dual-purpose vehicle which can be steered manually on a public highway or guided on a reserved track by mechanical or electronic means. Various projects have been mooted, with vehicles of different sizes from a conventional bus to a four-seater car. In most cases the vehicles would be coupled in trains on the reserved-track sections. The Washington analysis considers that the savings to be made at the transfer points would in practice be marginal, in relation to the cost penalty.

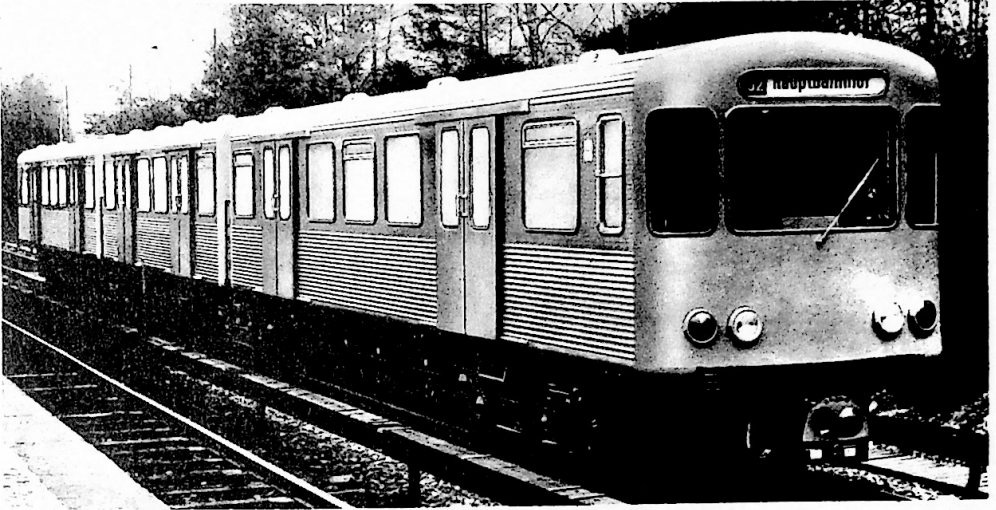
6.6 Conveyor Belt Systems

Excluding ground-effect-machines or hovercraft, which are dismissed in the Washington analysis as promising no transit applications, the other important means of transport is the conveyor-belt. Projects have been mooted in the United States, such as the Stevens-Adamson Carveyor, with 6-seater cars travelling at a speed of 16 km/h (10 mile/h), and the Immirzi belt system, capable of carrying nimble-footed pedestrians at speeds of up to 24 km/h (15 mile/h). Promoters' estimates suggest that such systems would be cheap in congested areas, where densities are high and journey distances are relatively short.

6.7 The Auto-Taxi System

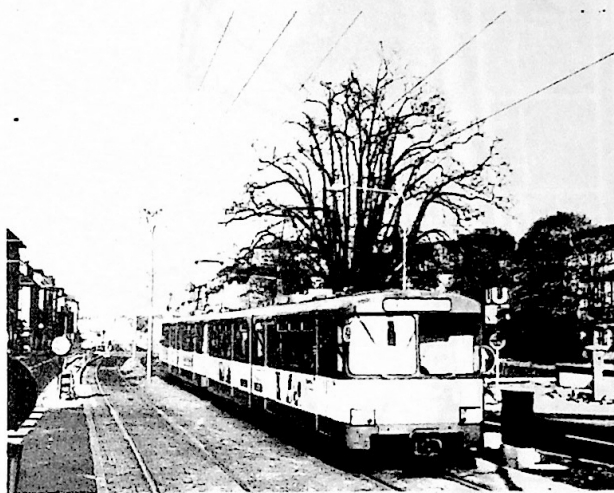
A recent entry in the field is the Auto-Taxi system, now being developed in this country by Brush Electrical Engineering Co. Ltd. who were once one of the major builders of trams. Small four-seater cars run on a fixed track under a centralised control system. Stations are located on loops off the 'main line' so that passengers can travel non-stop to their selected destination. The system has much in common with the classical tramway, but we are sceptical about its capacity to cope with peak traffic.

... suburban traffic, with stations at 2.5 km intervals and a maximum design speed of 120 km/h (75 miles/h). A motor-trolley-coach has been added because there is no immediate demand for the high performance of the equipment. The data given in the table is for the two-car set, which can be regarded as the best example of modern suburban railway practice.



7.2 Hamburger Hochbahn DT3 Eight-Axle Articulated Train-Set

This prototype articulated underground train-set was introduced in 1967 as a development of the DT2 six-axle unit. As with articulated trams, the elimination of bogies has brought considerable savings in weight. An important development over the DT2 series was that all axles are driven and the power/weight ratio is increased. Comparison between the Hamburg DT2 and the all-axle driven Berlin underground stock had shown that the latter, although faster in acceleration, actually consumed less power on a given journey, although the peak demand was of course greater. As the cost of electricity supply is determined largely by maximum demand, the faster stock could be dearer to operate, but on a large system the acceleration peaks of each train are less likely to coincide. Moreover, the higher journey speed would require slightly fewer trains.



7.3 Frankfurter Stadtbahn U6 Articulated Set

The Frankfurt Tramways have developed what is termed an underground railway car for its subways, the first stage of which was opened in late 1968. The vehicle is in fact a six-axle double-ended articulated tramcar with doors on both sides and a single step so that passengers can load from a 560 mm (1'-10") high platform or from a raised kerb only 320 mm (1'-2") high. Apart from a relatively short subway section in the town centre, the first route will be on reserved surface track with road crossings. An astute public relations campaign has given the town the prestige symbol of a Metro which is no more than a heavy tramway. Most of the other tram routes will be similarly gradually upgraded in a similar fashion.

Prototype cars were built in 1965 (for the IVA Exhibition) and in 1967, and a production batch of 30 units have been built. These have electronic control and are equipped for multiple-unit working in three-car sets.



7.4 Rhein-Haardt-Bahn 12-Axle Articulated Tramcar

These remarkable vehicles built in 1967 are the longest tramcars to be built in Germany and are a development from the six-axle cars which previously ran in pairs on this interurban tramway between Mannheim, Ludwigshafen and Bad Dürkheim. The main object of the 12-axle car is to enable one seated conductor to attend all passengers. One-man operation is hardly possible on this long route because of the diversity of fares. The car is designed for kerbside loading and has two intermediate steps up to internal floor height, as do all the following examples.



7.5 Kölner Verkehrs AG 6-Axle Articulated Tramcar

The Köln (Cologne) tramways have followed a similar policy of modernisation to the Frankfurt system, but with no pretence to doing anything more. The first section of the tram subways was opened in the autumn of 1968. The existing pattern of cars (single-ended with doors on the nearside only) are to be used, and loading will be from kerb-level platforms. This makes subway construction dearer, because outside platforms involve more excavation than a centre island platform, and turning loops or reversing triangles are necessary.

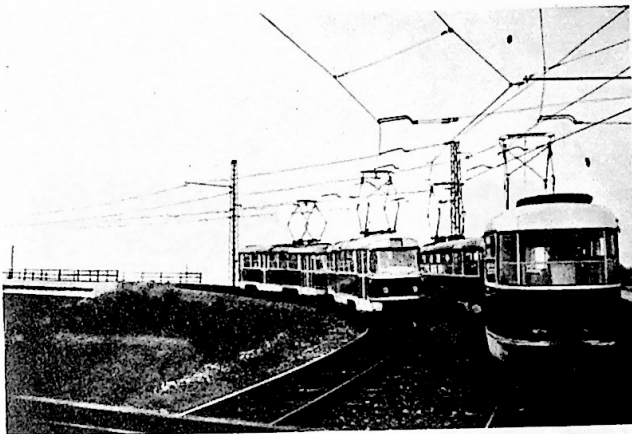
The tramcars are typical of recent production by Düwag of Düsseldorf, examples of which are to be seen throughout West Germany. The same type of cars are also to be seen (sometimes built under licence) in Wien (Vienna), Graz, Basel, Rotterdam and København (Copenhagen). They are generally designed to haul a bogie trailer at rush periods. In many cases, a centre articulated section and an extra bogie is added to a permanent extra capacity at a saving in weight. In March 1968, it was announced that sixty 8-axle articulated cars of this pattern were to be acquired to replace the existing tramcars in San Francisco.



7.6 Münchener Verkehrsbetrieb 4-Axle Articulated Tramcar and Trailer.

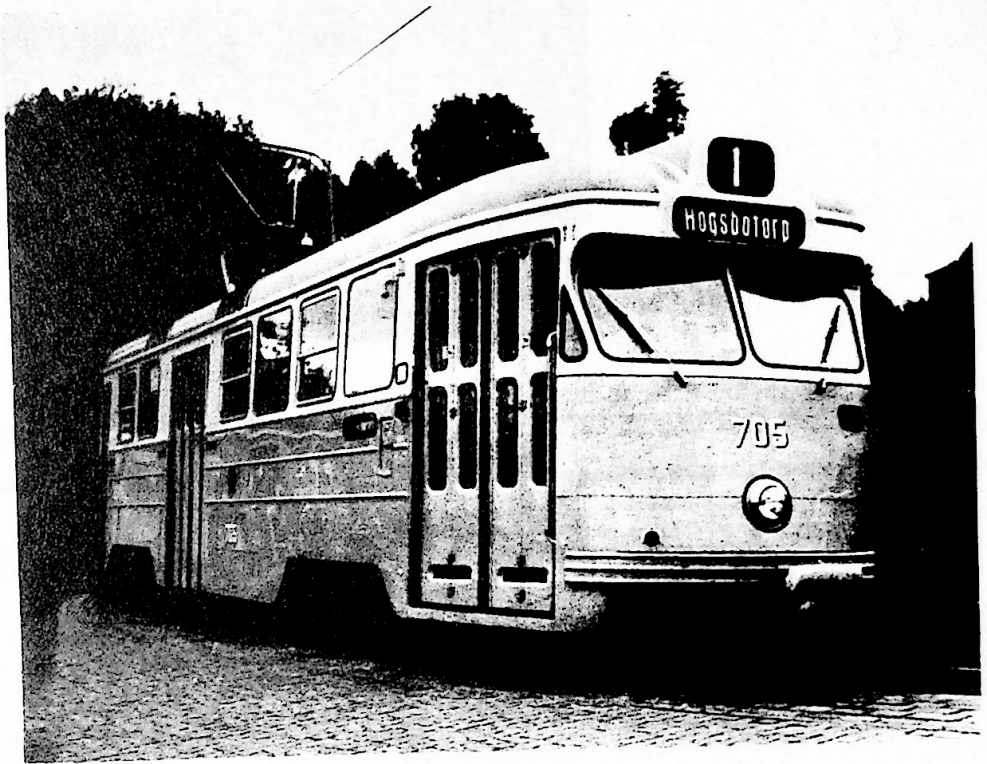
The advantages of an articulated vehicle on six, eight or more bogies can also be gained using longer bogie cars with an articulated body. A system has been devised by Waggonfabrik J. Rathgeber, München whereby the track configuration activates a linkage mechanism from the bogies to a central hinge in the body. This system is also used at Bremen and Bremerhaven, whose cars are built by Hansa Waggon-Fabrik, Bremen. A similar effect is obtained by using a sub frame spanning between the inner ends of the bogies and supporting the centre body pivot, while the body sections also rest on kingpins at the outer ends of the bogies. This system was used on cars built by the Esslingen locomotive works for Stuttgart, Reutlingen, Neunkirchen and Freiburg im Breisgau. When the factory was acquired by General Motors, production was taken over by the Rastatt Works, which delivered a further three new cars to Freiburg in 1968.

The prototype München (Munich) car was built in 1965 for the IVA Exhibition in 1965, and a total of 40 cars is being delivered. The motor cars are designed to haul a similar trailer, and they are remarkable for the low weight/passenger ratio.



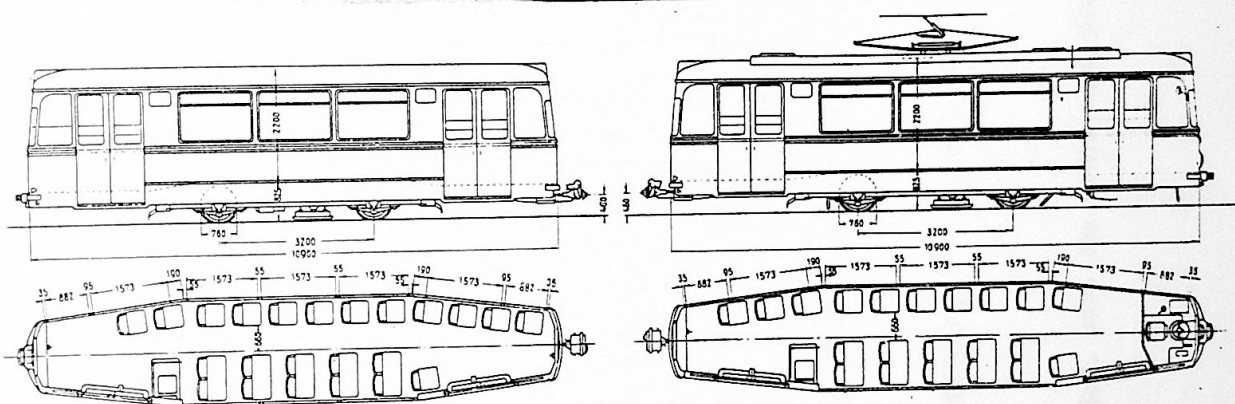
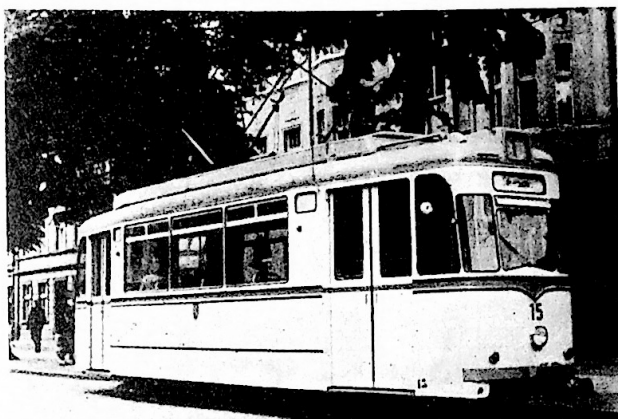
7.7 Tatra T3 PCC-type Bogie Tramcar

Several versions of the American PCC design of 1935 have been produced elsewhere, but the most numerous is the Czech Tatra T series built since 1952 under licence. The current T3 model dates from 1962 and is now being mass-produced at a rate of nearly 1000 per year for the East European market. The PCC principle has its violent opponents and its devoted adherents. Its critics claim that the concept of a streetcar to suit American traffic conditions of the 1930's is out of date, and that the car is extravagant in its current consumption. It can be stated fairly in its favour that the system was remarkably advanced for its time, that it is robust, and that the system can be modified for special requirements, such as high maximum speed. Moreover, it is now being mass-produced and is therefore relatively cheap. It is also claimed that power consumption is not excessive on a reserved track free from traffic congestion. The ČKD Tatra works in Praha (Prague) produce a six-axle articulated variant with lower acceleration and also a bogie car for hauling trailers. The maximum speed quoted is based on the Czech official speed limit for trams, but we have ridden on these cars at up to 80 km/h on the express tracks at Košice. The low proportion of seating is due to the demand of Eastern European operators, and this could be raised without any complication. In Western Europe, PCC bogie cars and six-axle articulated cars of the same basic type have been produced in smaller quantities in Italy and ACEC of Charleroi, Belgium for Antwerpen, Bruxelles, Bruges, den Haag (The Hague), St. Etienne and Marseille.



7.8 Göteborgs Sparvagn M28 Bogie Tramcar

This car is a Swedish development of the PCC principle using the Tremiac electronic control instead of the PCC electro-mechanical system. Car performance is much the same, except that acceleration is slightly lower due to the extra weight because of the wider body. The latest development of the series was introduced in 1965 and costs SKr 330000. The electrical equipment is by ASEA. A smaller version of this design was built for the Norrköping system. The Göteborg (Gothenburg) cars are designed for multiple-unit working.



7.9 Gotha M62 Single-Truck Tramcar

This is one of the last single-truck tramcar designs still in production, which is due to cease in 1968. The design is a refinement of traditional German tramcars, suitable for running with one or two trailers. Performance of the cars is not outstanding but they are designed to need a minimum of maintenance, and are claimed to have a life of 30 years or about 2.4 million km. Their initial cost is MDN 132 000. To overcome staffing problems in East Germany, an articulated version of the same basic type, with two sections rigidly supported on single trucks and a suspended centre section has been produced, but its performance is no better. We would not recommend this type for a new installation, but we have included it for comparative purposes.

7.10 Comparative Table

Example	7.1	7.2	7.3	7.4	* 7.5	* 7.6	7.7	7.8	* 7.9
No. of Axles	8	8	6	12	6 + 4	4 + 4	4	4	2 + 2 + 2
Maximum Speed (km/h)	120	80	80	80	65	80	65	70	60
Acceleration (m/sec ²)	0.6	1.2	1.0	ca.1.2	ca.1.2(1.0)	ca.1.4(1.1)	1.8	1.6	ca.1.0 (0.6)
Motors (no. x kW hourly)	8x 173	8 x 80	2 x150	2 x150	2 x 150	4 x 80	4 x44	4 x 44	2 x 60
Body Length (m.)	50.04	39.52	23.0	38.55	21.12+14.00	16.70 + 16.70	14.0	14.16	11.6 +11.6 + 11.6
Body width (m.)	2.86	2.50	2.65	2.20	2.50	2.35	2.50	2.65	2.20
Weight unladen (tonnes)	ca.95	45.5	29.3	34.4	22.5 +11.00	21.5 + 14.0	15.2	16.5	12.5 + 8.0 + 8.0
Seats	127	116	64	118	29 + 35	44 + 41	24	36	22 + 24 + 24
Crush Capacity	411	364	231	320	213 + 145	158 + 177	120	124	82 + 90 + 90
Power/Weight ratio (kW/tonne)	ca.14.3	14.13	10.5	8.82	13.3 (8.92)	14.2 (0.90)	11.6	10.17	9.6 (4.25)
Weight/Passr. ratio (tonne/passr.)	ca.0.232	0.125	0.124	0.106	0.106(0.094)	0.136(0.10)	0.127	0.133	0.152 (0.108)

* Where Cars designed for working with trailers are included, data for motor cars plus trailer are shown. Figures in brackets refer to the sum of both motor and trailer(s).

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